Computer Simulation from Electron Beam Lithography to Optical Lithography

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ABSTRACT

Simulation of electron beam lithography and optical lithography has been combined to investigate the influence of a distorted photomask feature on final photoresist image. Unlike the previous optical lithography simulation which was based on ideal mask design, the combined simulation has shown that mask distortion due to electron proximity effect play an important role in worsening the optical proximity effect, which is particularly critical at subresolution optical lithography.

1. INTRODUCTION

Optical lithography is a key step in micro device fabrication. Starting from a photomask, the final feature dimension of a device depends on how truthfully an optical imaging system can transfer the mask layout to a resist image on a substrate. With continuously shrinking of device feature dimension below sub-half micron, diffraction limit in conventional photolithography systems has caused feature distortion which is known as optical proximity effect. Software modelling tools have played a crucial role in estimating the effect and proposing various correction schemes [1-2]. However, existing optical lithography simulation packages can only simulate an ideal design layout while in reality a photomask has to be fabricated by other lithography tools, mostly electron beam lithography, which introduces its own distortions. A real mask pattern is no longer an ideal design but with distortions caused by electron proximity effect. Therefore the distortion in final resist images are due to optical proximity effect compounding electron proximity effect from the mask. Software tools for electron beam lithography simulation and optical lithography simulation have been developed and commercially available [3-4]. However, no modelling tools exist which can link the two simulations to demonstrate an optical lithography image which results from a photomask distorted by electron proximity effect.

In this paper, electron proximity effect and optical proximity effect have been studied by the modelling packages of MOCASEL (MOnte CAlor Simulation of E-eam Lithography) [5] and COMPARE (COmputer Modelling of Photolithgraphy And Resist Evaluation) [6]. The two software packages were then combined to simulate from electron beam lithography to optical lithography to mimic the whole process of mask fabrication and optical imaging of resist. The difference in resist image distortion is evidently demonstrated between the combined simulation and conventional optical lithography simulation based on ideal designs. The distortion is much worse for smaller feature dimension in which the contribution from electron proximity effect is greater.

2. ELECTRON PROXIMITY EFFECT

Electron proximity effect has been a major obstacle for achieving fine resolution in electron beam lithography. As charged particles, electrons undergo forward and backward scattering when exposing a resist layer on a substrate. Fig.1 shows typical electron trajectories simulated by the Monte Carlo simulation package MOCASEL. The simulation assumed electrons with 10keV energy exposing on a resist coated photomask substrate (chrome on quartz plate).

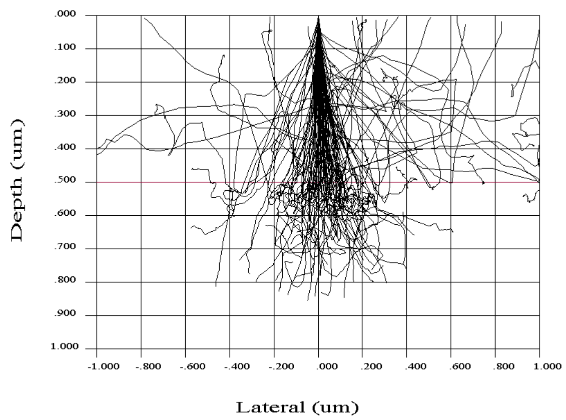


Fig.1 Electron scattering trajectories in resist coated photomask at 10keV energy

The trajectories show that electrons impinging at a single point on the resist surface have scattered over 2µm range inside the resist layer. The effect of this scattering is that an initial fine electron beam becomes much broadened in resist, resulting in blurred image and distorted features. Some closely adjacent features may even be bridged due to the scattering, as shown in Fig.2 which shows a simulated 3D resist image. The fine resist line cannot be resolved because of electron scattering from adjacent large pads, which is the so called electron proximity effect.

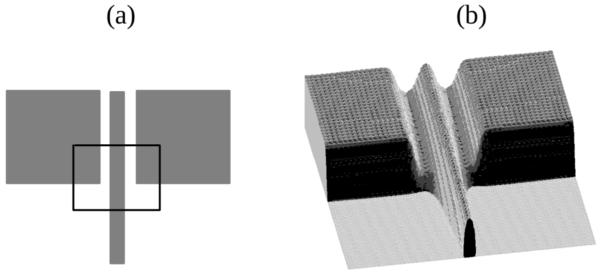
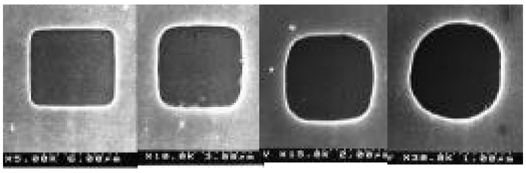


Fig.2 (a) Original design showing a fine line between two large pads and (b) Simulated 3D resist image

There are a number of factors which influence the electron proximity effect, such as electron energy, resist thickness, substrate material and pattern density. Generally, higher electron energy and thinner resist layer will have less proximity effect. Substrates of lighter material will reduce the backscattering electrons and low feature density will make the proximity effect less significant. However, in the case of making photomasks by electron beam lithography, some of the conditions are unfavourable to proximity effect reduction. Electron beam energy used in photomask exposure is as low as 10 keV. Higher beam energy is not preferred because it requires higher exposure dose which increases considerably the exposure time. A chrome layer is required for a photomask plate which causes more backscattered electrons, as can be seen from the electron trajectories in Fig.1.

One of the typical problems caused by proximity effect in electron beam exposure of photomasks is pattern distortion. A square pattern is no longer a square with sharp corners. Such distortions are much server for small feature dimensions, as is shown in Fig.3 the real mask patterns. These squares were patterned by electron beam lithography. It is apparent that the smaller the square the severer the distortion.

(a)



6µm 3µm 2µm 1µm

(b)

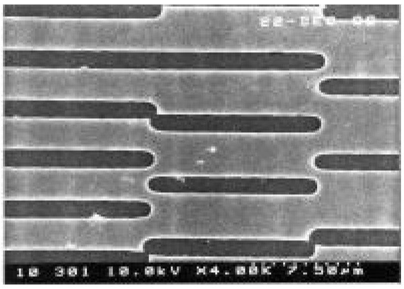
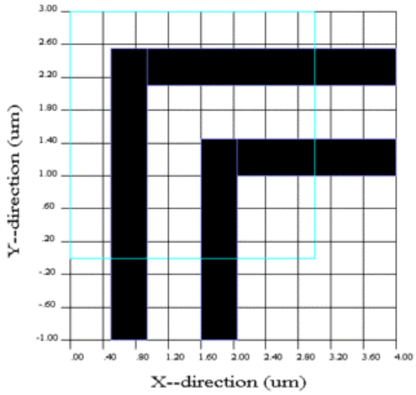


Fig.3 Fabricated (a) square features of difference sizes and (b) 1.5µm line features on optical mask by electron beam lithography

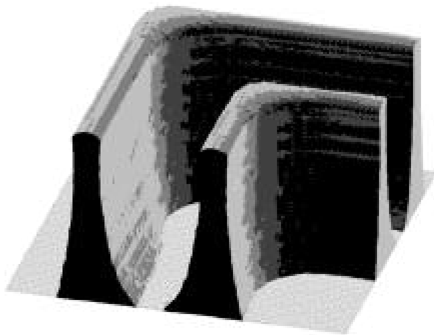
3. OPTICAL PROXIMITY EFFECT

Optical proximity effect is caused by non-uniform distribution of optical intensity, which is too strong in some parts of a pattern and too weak in some other areas. Such non-uniform distribution of intensity is due to the difference in light diffraction at different parts of a feature. The effect is much pronounced when a mask feature dimension is approaching the illumination wavelength. The effect is demonstrated by computer simulation shown in Fig.4. Fig.4(a) is a pattern design with feature width of 0.4µm. Fig.4(b) is the 3D simulation of resist image from the design by the optical lithography simulation package COMPARE. The optical wavelength is assumed to be 0.365µm. The photoresist is of negative tone. The resist image is no longer a true rectangular feature due to optical proximity effect.

Optical proximity effect is typically represented by corner rounding, as shown in Fig.4(b), or line end shortening of design features. Fig.5 gives a comparison between the original design and the simulated optical intensity contour [7]. To reduce the optical proximity effect, many correction schemes have been proposed. These schemes are basically modification of the pattern design with added serifs or jogs. An example of pattern design after proximity effect correction is shown in Fig.6. Such correction has become necessary for sub-resolution optical lithography.



(a)



(b)

Fig.4 (a) Optical mask design with minimum feature width of 0.4µm and (b) the simulated 3D resist image from the design

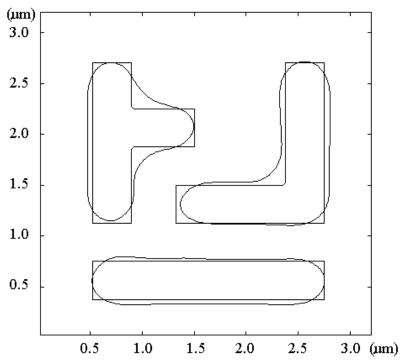


Fig.5 Optical intensity contour compared with original design

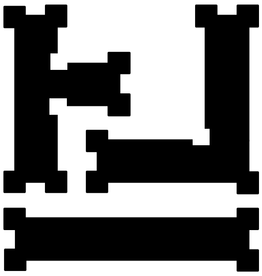


Fig.6 Modification of pattern design to correct optical proximity effect

4. COMBINED SIMULATION

Both electron beam lithography and optical lithography simulations have been well established. There are commercial software tools available. The software for optical lithography simulation in particular has become an integral part of process development tool set. These software tools can optimise process conditions, evaluate new processes and predict resist profiles before going through fabrication trials. However, all these tools are doing optical lithography simulation based on ideal designs which directly come from design station. In reality, optical lithography is carried out using a photomask which is fabricated by other lithography tools, such as electron beam or laser beam lithography. It has been shown in previous section that these tools for making the masks have their own proximity effect, therefore, introduce distortions to the mask. A real mask is no longer the same as the ideal design, as shown in Fig.3.

Both electron beam proximity effect and optical proximity effect have been demonstrated in the previous sections using the computer simulation packages MOCASEL and COMPARE. A new interface tool has been developed which can take a pattern generated by MOCASEL simulation and feed to COMPARE simulation package. The combined simulation can mimic the true optical lithography process where a mask fabricated by electron beam lithography is used in optical imaging. An example of the combined simulation is shown in Fig.7.

Starting from the design shown in Fig.7(a) where the feature width is 1.5µm, electron beam lithography simulation is carried out with MOCASEL package, assuming 10keV beam energy and 0.4µm positive resist layer coated on a optical mask plate (0.1µm chrome on quartz substrate). The 3D electron beam resist image is shown in Fig.7(b). The chrome layer at the opening region of resist layer will be etched away to form the transparent area for optical lithography. Fig.7(c) is the mask feature after removal of chrome. Compared Fig.7(c) with Fig.7(a) it is apparent that the real mask features are not the same as the original design. Electron proximity effect has resulted in rounded corners instead of sharp ones. The mask pattern in Fig.7(c) is then used for optical lithography simulation with the COMPARE package, assuming 365nm illuminating wavelength, 0.5 numerical aperture, 0.5 partial coherence and negative photoresist of 1.12µm thickness. Fig.7(d) is the simulated 3D photoresist image.

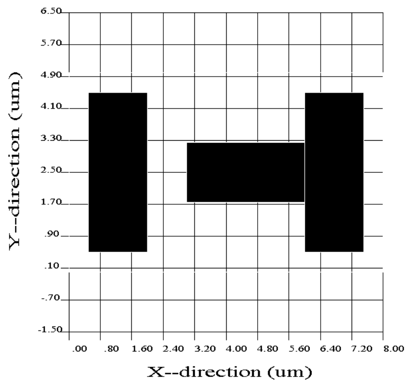


Fig.7(a) Original mask design composed of ideal rectangles

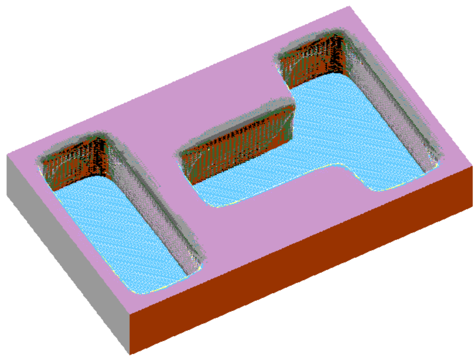


Fig.7(b) Simulated 3D electron beam resist image from the original design

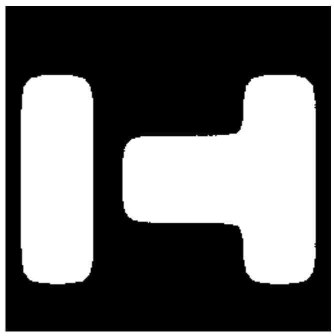


Fig.7(c) Real mask pattern fabricated by electron beam lithography

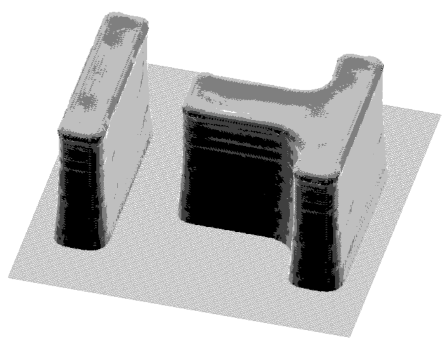


Fig.7(d) 3D Photoresist image simulated with the real mask shown in (c)

To compare the difference in optical lithography between an ideal mask feature and a real mask feature, the simulation of ideal design shown in Fig.7(a) is also carried out. The 3D resist image is shown in Fig.7(e). A careful comparison between Fig.7(c) and (e) will reveal the difference in resist profiles. The resist profile from the ideal design has sharper corners than the one from the real mask.

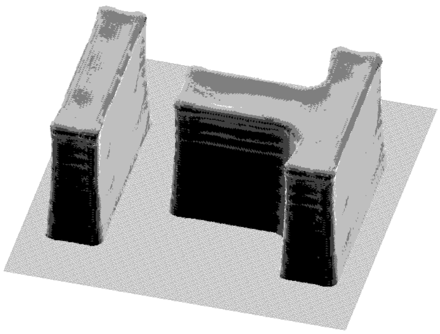


Fig.7(e) 3D photoresist image simulated from the ideal design shown (a)

The simulated feature size in Fig.7 is 1.5μm which is big compared with 0.365μm illuminating wavelength in the optical lithography. Therefore, the difference in resist profiles between real mask and ideal mask is very small. The difference only becomes significant if the mask feature dimension becomes comparable with the wavelength. The optical lithography in mainstream VLSI fabrication has been extended to the regime where optical proximity effect is a significant limiting factor for achieving feature fidelity at integrated circuit level. Industry has been experimenting different correction schemes to overcome the limitation caused by optical proximity effect. These schemes, such as shown in Fig.6, require some of the mask feature dimension less than the optical wavelength. The distortion in mask will contribute significantly to the distortion in optical imaging.

To demonstrate such effect, a mask feature shown in Fig.8(a) has been simulated with both MOCASEL and COMPARE. The design is a rectangular shape with serifs on each corner. The main feature size is 3μm and the serifs are of 0.7μm. Each serif protrudes 0.35μm out of the main feature.

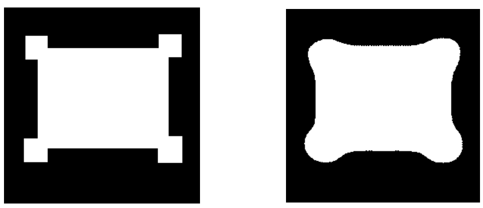
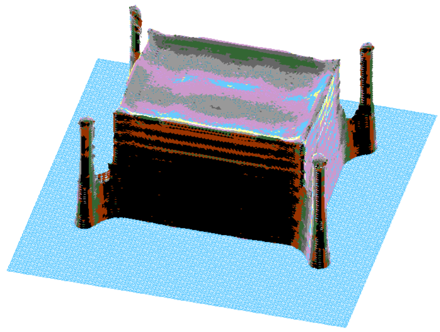
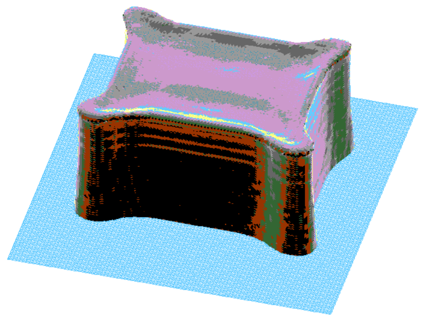


Fig.8 (a) Original mask design with serifs protruding out and (b) real mask pattern by electron beam lithography

The simulation of electron beam lithography produced a real mask pattern shown in Fig.8(b). Those serifs in the original design have all become rounded due to electron proximity effect. Simulation of optical lithography were carried out with both the original design and the real mask pattern. The 3D photoresist profiles are shown in Fig.9. Both resist profiles were simulated at same conditions, such as illuminating wavelength, numerical aperture, exposure dose and development time. The only difference is the mask used. Fig.9(a) is the resist image produced from the ideal design and Fig.9(b) is the one from the real mask. The difference between the two profiles are significant.



(a)



(b)

Fig.9 (a) Simulated 3D resist profile from the ideal mask and (b) 3D resist profile from the real mask

5. SUMMARY

Simulations of electron beam lithography and optical lithography have been combined to investigate the effect of distorted mask on optical imaging of photoresist. Optical proximity effect is worsened when compounding the mask distortion caused by electron proximity effect. The distortion in resist profile is greater for smaller features.

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